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Performance analysis of a dynamic reservation multichannel local area network

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Abstract

Title of Thesis: Performance Analysis of a Dynamic Reservation Multichannel Local Area Network

Abubakar Ibrahim, Master of Science in Electrical Engineering, 1990

Thesis Directed by: Dr. Irving Wang, Assistant Professor

A reservation multiaccess protocol is proposed to be used on multichannel local area networks. This protocol is advantageous for networks supporting integrated services. The delay and throughput performance for message transmission are obtained by analysis. The delay performance of the protocol is similar to the M-CSMA/CD/IC multichannel network proposed by Marsan and Roffinella. It is found that the reservation protocol can provide better throughput-delay characteristics when the fraction of the total available bandwidth allocated to data is increased. It is also observed that the maximum throughput increases with the increase in the number of channels when the total bandwidth is uniformly divided by the channels.

2) PERFORMANCE ANALYSIS OF A DYNAMIC RESERVATION MULTICHANNEL LOCAL AREA NETWORK

by
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Chapter 1

INTRODUCTION

Local area networks (LAN) are increasingly becoming important in offices, factories and universities. The reason for such a rapid development of LAN technology lies in the need to connect together a collection of computers, terminals and peripherals of an organization situated in close proximity. This has resulted in a lot of research directed towards developing efficient multi-access techniques [11,17,21]. Since the multiaccess protocol defines the way in which the transmission bandwidth is shared among the network users , it has a great effect on the utilization of the communication channel.

Local area networks can broadly be classified into two main categories according to their transmission structure:

1. Broadcast bus systems

2. Ring systems

Each of these systems have their drawbacks and advantages. Ring systems consist of point-to-point links connecting users in a circular manner. These systems offer high data rates but the presence of many active insertions on the communication channel poses reliability problems. Broadcast bus systems on the other hand are much more reliable since no active components are found in the communication channel. However, one of the drawbacks of the bus system is that its performance depends on the length of the transmission media. Specifically it depends on the ratio of network end-to-end propagation delay to packet transmission time. At large values of this ratio, the overall system capacity decreases linearly with its reciprocal and this may result in a considerable degradation in system performance. This problem has been worsened by the current trends towards higher bandwidth media and expanding the geographical coverage in local area networks.

Designing very high bandwidth single channel networks has two major problems, namely; high cost and low reliability. The use of multichannel architectures [3,4,11,22] is one way of combating this problem. Figure 1.1 illustrates a multichannel network with N parallel channels which are usually obtained by evenly dividing the total available bandwidth. For example, a total capacity of 100Mbps can be provided by ten 10Mbps channels working in parallel. This approach has several advantages:

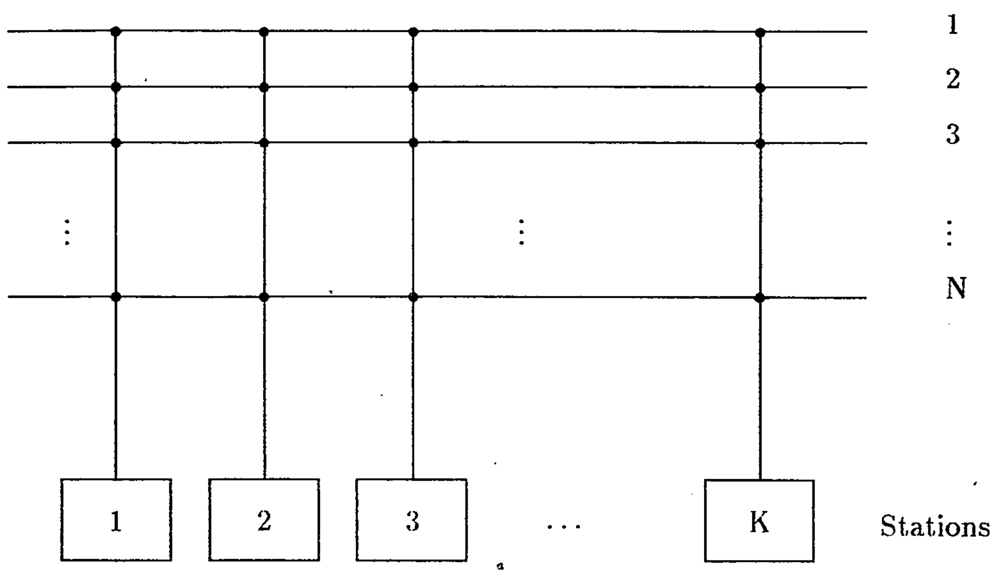

Figure 1.1: Multichannel network architecture

- It increases the network capacity by operating on slow speed channels so that the end-to-end propagation delay becomes a small fraction of the packet transmission time. In this way the channels can be utilized more efficiently.

- It can utilize existing interface components based on proven medium speed technologies.

- It provides higher reliability by offering alternate paths for communication between users.

- Its modular structure allows flexibility for future expansion.

Marsan and Roffinella [11] proposed a multichannel bus architecture (CSMA/CD/IC) for local area networks in which each station was connected to all the channels in the network. The channel selection mechanism proposed in [11] is an integral part of the media access technique in that the channels are dynamically assigned to stations depending on the current state of the system (i.e., the system backlog and availability of channels).

The multichannel network proposed by [11] was found to improve the system capacity and average message delay significantly when compared to the single channel. However, the inherent drawbacks due to the non-deterministic behaviour of the carrier sense multiple access schemes (CSMA and CSMA/CD) are still present in the multiple CSMA networks.

1.1 Objective

The aim of this thesis is therefore to propose a reservation multichannel network which will minimize the effects of the drawbacks of the CSMA/CD protocol. Our proposed protocol is derived from the Dynamic Split-Channel multiple Access (SRMA) protocol which was developed in [20]. We apply the SRMA protocol, which was intended for single channel networks, on the multichannel architecture. We also investigate the system performance of our proposed protocol and compare it to that of the CSMA/CD/IC. We use the CSMA/CD/IC because of its well known delay-throughput properties.

1.2 Summary of Results

The results obtained from this study show that the proposed reservation multiaccess scheme increases the maximum throughput as the number of channels is increased for an evenly divided bandwidth. It is also possible to obtain better throughput-delay performance when compared to the CSMA/CD/IC protocol.

1.3 Outline

The rest of this thesis is organized as follows. Chapter two introduces some of the media access protocols that are available. Chapter three gives a detailed description of the proposed protocol and its performance evaluation. The results and the conclusion are presented in chapter four and chapter five respectively.

Chapter 2

MULTIACCESS PROTOCOLS

2.1 Introduction

Multiaccess protocols differ by the static or dynamic nature of the bandwidth allocation algorithm, the centralized or distributed nature of the decision making process, and the degree of adaptivity of the algorithm to changing needs. As mentioned in the previous chapter, different channel access protocols have been proposed [6,17] and can be classified as:

- Fixed Assignment Techniques
- Random Assignment or Contention Techniques
- Demand Assignment Techniques

2.2 Fixed Assignment Techniques

Two popular forms of these techniques are frequency division multiple access (FDMA) and time division multiple access (TDMA).

2.2.1 FDMA and TDMA

Both FDMA and TDMA allocate the channel bandwidth to the users in a static fashion. FDMA consists of assigning to each user a fraction of the bandwidth and confining its access to the allocated subband.

TDMA consists of assigning fixed predetermined channel time slots to each user; the user has access to the entire channel bandwidth, but only during its allocated slots.

Both FDMA and TDMA work well under heavy buffered traffic and with a small and fixed number of stations. But if the number of stations is large and continuously varying, and if the traffic is bursty (which characterizes interactive applications), dividing the available bandwidth is inefficient. The basic problem with these schemes is that if some stations have nothing to send, their bandwidth remains unused, thereby wasting the channel bandwidth.

2.3 Random Assignment or Contention Techniques

These protocols are characterized by the lack of strict ordering of the stations contending for access to the channel. In a random access technique, a station is free to broadcast its messages at a time determined by itself without coordination with the other stations. Systems in which multiple stations share a common channel that can lead to conflicts, are widely known as contention systems.

2.3.1 ALOHA

The *pure* ALOHA protocol was first used in the ALOHA system, a single-hop terminal access network developed in 1970 at the University of Hawaii, employing packet-switching on a radio channel [1]. In *pure* ALOHA a user is allowed to transmit any time it desires. A successful transmission would induce an acknowledgement from the destination which informs the transmitter that no conflict occurred. Otherwise a collision is assumed and a retransmission is scheduled. To avoid continuously repeated conflicts, the retransmission delay is randomized across the transmitting devices, thus spreading the retry packets over time.

An improved version, known as *slotted* ALOHA [14,19] is obtained by dividing time into slots of duration equal to the transmission time of one packet (assuming constant-length packets). Each user is required to synchronize the start of transmission of its packets to coincide with the slot boundary. The maximum channel efficiency for the *pure* ALOHA and *slotted* ALOHA is 18 percent and 36 percent respectively. Although this maximum efficiency is low, the ALOHA schemes are superior to fixed assignment schemes when a large population of bursty users is involved.

2.3.2 Carrier Sense Multiple Access (CSMA)

In carrier sense multiple access any station with a packet to transmit basically follows the same procedure as in the *slotted* ALOHA scheme. However, before transmission it listens to the channel (Carrier Sense) so as to avoid collisions. There are two main CSMA protocols known as *non-persistent* and *p-persistent* CSMA depending on whether the transmission by a station which finds the channel busy is to occur later or immediately following the current one with probability p. Many variants and modifications of these two schemes have been proposed. In all these schemes however, when a station finds out a transmission was unsuccessful, it reschedules the transmission of the packet according to a randomly distributed retransmission delay.

In *non-persistent* CSMA, a ready terminal senses the channel and operates as follows:

1. If the channel is sensed idle, it transmits the packet.

2. If the channel is sensed busy, then the terminal schedules the retransmission of the packet to some later time according to the retransmission delay distribution. At this new point in time, it senses the channel and repeats the algorithm described.

The *p-persistent* CSMA protocol operates as follows:

1. If the channel is idle, it transmits the packet with probability p.

2. If the channel is busy, it waits until it becomes idle, and then with probability p the station transmits the packet, and probability $1 - p$ it delays the transmission of the packet by some time. At the end of the this delay period, the station repeats this above procedure.

A variation of the CSMA protocol which allows the stations to monitor the channel to see if they agree with the packets being transmitted is known as carrier sense multiple access with collision detection (CSMA/CD) [18]. When a collision is detected, the detecting station immediately aborts its transmission and sends a signal to prevent other stations from transmitting. This protocol first used by Ethernet [12] reduces the bandwidth wasted as well as the transmission delays caused by collisions. However, like CSMA, it cannot completely eliminate collisions.

2.4 Demand Assignment Techniques

This type of protocol requires that one communication channel is explicitly adopted to carry the control information which is issued by the stations and used to determine the access order for the shared channel. It is referred to as demand assignment in the sense that, unlike fixed assignment, the bandwidth remains unwasted by avoiding assignment of the channel to the idle stations. Further, the channel would not be wasted due to the collisions, since no collisions occur for this type of protocol. There are two types of demand assignment namely:

1. Centrally Controlled Demand Assignment
2. Demand Assignment with Distributed Control

2.4.1 Centrally Controlled Demand Assignment

Polling Systems

Polling is one of the methods used to centrally control access to the communication bandwidth in packet oriented systems. The central controller sends polling messages to the terminals, one-by-one, asking the polled terminal to transmit. If the polled terminal has something to transmit it goes ahead otherwise it sends a negative reply to the controller, which then polls the next terminal in sequence. Polling has been found to be efficient

1. when the round-trip propagation delay is small
2. the overhead due to the polling message is low
3. the user population is not a large bursty one

Split-Channel Reservation Multiple Access (SRMA)

This is an attractive alternative to polling which uses an explicit reservation technique. In the dynamic reservation system, it is the terminal which makes a request for service on a channel when it has a message to transmit. The central controller manages a queue of requests and informs the terminal of its allocated time.

Since the channel is the only means of communication among the terminals the main problem is how to communicate the request to the central controller. The contention on the channel of the request packets is of exactly the same nature as that of the data packets. In the split-channel reservation multiple access (SRMA) scheme the available bandwidth is frequency divided between the two types of data. The available bandwidth is divided into two channels: one is used for transmission of control information and the second is used for the data messages. With this configuration, there are many operational modes. In the request/answer-to-request/message scheme (RAM), the bandwidth allocated for control is further divided into two channels: the request channel and the answer-to-request channel. The request channel is operated in a random access mode (ALOHA or CSMA).

Upon correct reception of the request packet, the scheduling station computes the time at which the backlog on the message channel will empty and transmits an answer packet back to the terminal, on the answer-to-request channel, containing the address of the terminal and the time at which it can start transmission.

Another version of SRMA, called the RM scheme, consists of two channels: the request channel and the message channel. When correctly received by the scheduling station, the request packet joins the request queue. Requests may be serviced on a first-come first-served basis or any other scheduling algorithm. When the message channel is available, an answer packet is transmitted by the controller to the terminal on the message channel. After hearing its own identification the station begins transmitting its message. If it does not hear its own identification within a certain time after the request is sent, the original request packet is assumed to be unsuccessful. The request packet is then retransmitted.

The SRMA scheme is found to have a better performance when the request channel is operated in a *slotted nonpersistent* CSMA as compared to ALOHA [20].

2.4.2 Demand Assignment with Distributed Control

Some of the distributed control techniques fall into the control-token, slotted and register insertion categories.

Token Passing Techniques

The control-token-passing scheme is based on a control token that is passed from node to node around a loop. The control token is a special bit pattern which indicates the state of the channel (free or busy). A free token represents an access permission to the channel. A station ready to transmit waits for a free token, changes it to a busy token and puts its packet onto the ring. The packet can, in principle be of any arbitrary length. The sending station is responsible for removing its own packet from the ring. At the end of its transmission, it passes the access permission to the next station by generating a free token. This type of protocol allows only one node at a time to transmit a message of variable length.

Slotted Protocol

In the slotted protocol, a series of fixed-sized slots are passed continuously around the loop. A full or empty indicator within the slot header is used to signal the state of the slot. Any station which wants to transmit waits for the first empty slot passing by, sets its full/empty indicator to full, and places its data in it. When the sender receives back the occupied slot, it changes the full/empty indicator to empty. The protocol allows more than one node to simultaneously transmit messages but each transmission must fit within the fixed length slot.

Register-insertion

This protocol derives its name from the fact that each station has a shift register in its interface. In this scheme a message awaiting transmission is first loaded into the shift register. When the channel becomes idle or between the transmission of two consecutive messages, the message is inserted into the loop by shifting it from the register. Any incoming message is shifted into the register. The protocol allows for the simultaneous transmission of variable-length messages by more than one node and is therefore a generalization of the token-passing and slotted protocols.

Chapter 3

THE PROPOSED RESERVATION PROTOCOL

3.1 Network access protocol

Figure 3.1 shows a multichannel network with N channels. The network includes one channel for signalling and the remaining N-1 channels used for message transmission. The signalling channel is used for channel reservation, acknowledgements and system setup etc. The signalling channel could use any of the media access techniques available. However, from previous results it has been shown that random access techniques suggest themselves as a method for multiplexing the requests on the channel [17]. In [19] it has been shown that the reservation channel using nonpersistent CSMA performs better than the one with ALOHA. For our proposed protocol we have chosen the nonpersistent CSMA/CD protocol for the signalling channel because it outperforms CSMA [18].

In the reservation scheme a terminal first makes a request for service

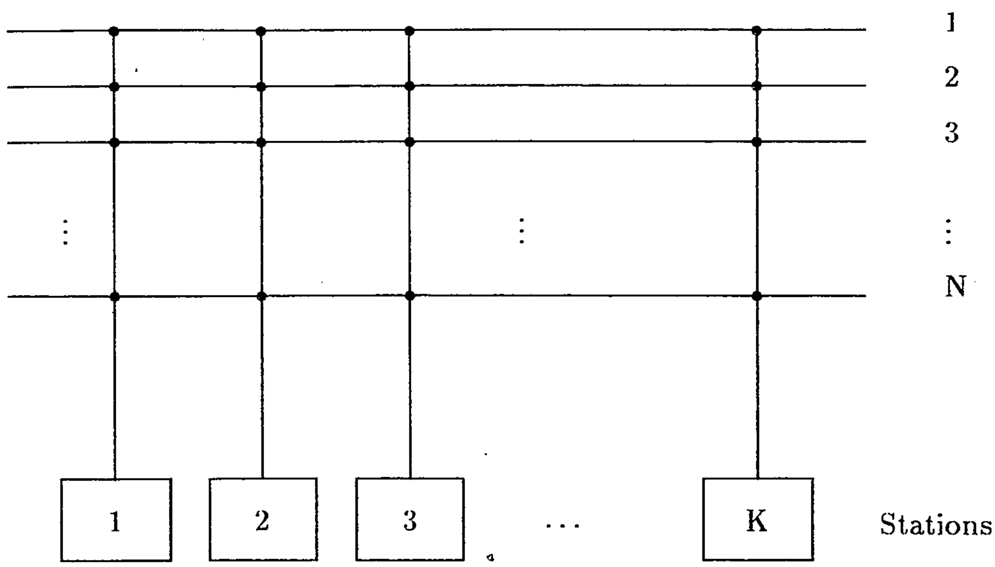

Figure 3.1: A multichannel network

on the signalling channel whenever it has a message packet to transmit. It makes this request by contending on the signalling channel to transmit a channel reservation signal R (Figure 3.2) to the controlling station. If a terminal succeeds in transmitting a reservation packet the immediately following slot is reserved for the controlling station to reply with an answer packet containing the time it can start transmission, and on which channel.

The controlling station maintains a table recording the current information on the message channels. A typical table is shown in Table 3.1. The second column indicates the channel status. B (busy) indicates that the channel is not available for reservation, R (ready) indicates that the transmission on the channel is about to finish and is now open for reservation.

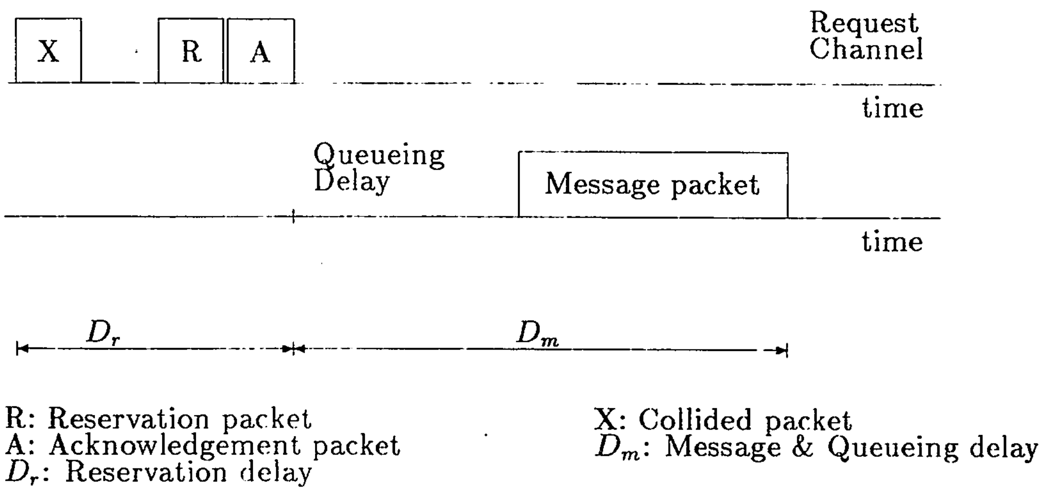

Figure 3.2: Channel access signalling

I (idle) indicates that the channel is allowed for immediate transmission. The third and fourth columns show the numbers of the transmitting and receiving station respectively. When the scheduling station receives a request it uses the information in the channel status table and its scheduling algorithm to make a reservation.

3.2 Model

The network is defined by the number of stations N, the number of channels m of total bandwidth W in bits/s. Each of the message channels has the same bandwidth W_m/m.

Channel Number	Channel Status: B/R/I	Transmit Station	Receive Station
1	B	2	15
2	R	12	1
.	.	.	.
.	.	.	.
9	I	-	-
10	I	-	-

Table 3.1: A typical status table of the network

Model Assumptions

In performing the analysis, we will assume that:

1. The N stations collectively generate Poisson data traffic at a rate of λ messages/second.

2. Successful reservation requests arrive at the central controller in a Poisson manner at a rate of λ.

3. Reservation and message channels are error-free.

4. Processing delays at the central controller and terminals are negligible.

5. The lengths of data messages are exponentially distributed.

The following notation is also introduced in the model:

W : total bandwidth
W_m : total bandwidth for message channels
W_r : bandwidth assigned to request channel
b_m : message packet size
b_r : request packet size
b_a : answer packet size
θ : fraction of total bandwidth assigned to message channels W_m/W

We denote T_m to be the message packet transmission time on a channel

$$T_m = (m - 1)b_m/W_m$$

Similarly T_r is the transmission time of a request packet and is given by

$$T_r = b_r/W_r$$

The transmission time of the answer packet T_a is also given by

$$T_a = b_a/W_r$$

We also define

$$\eta_a = b_a/b_m$$

and

$$\eta_r = b_r/b_m$$

3.3 Performance Analysis

In the proposed protocol, two performance parameters of interest are defined as

1. Delay D: the time elapsed from the moment a message is ready for transmission up to the time it is transmitted successfully.

2. Throughput S: the average number of packets per packet transmission time on the entire bandwidth.

3.3.1 Delay-Throughput Analysis

The total delay D of our protocol consists of two parts, namely:

1. the Reservation channel delay D_r

2. the Message channel delay D_m

Resevation Channel Delay

Assume that both request and acknowledgement packets contain the same information i.e. $b_a = b_r$ and $\eta_a = \eta_r = \eta$. Therefore

$$W_r = W_a = \frac{(1-\theta)W}{2} \tag{3.1}$$

We assume that all the stations collectively generate Poisson traffic at a rate of λ packets/s, and under steady state conditions, λ is also the throughput. This throughput is then normalized to the maximum generation rate that the total bandwidth W can ever handle i.e. W/b_m. The normalized throughput S is therefore expressed as

$$S = \frac{\lambda b_m}{W} \tag{3.2}$$

Since our reservation channel is operated in the CSMA/CD mode, the input rate S_r, normalized to the packet transmission time on the request channel under consideration is given by [20]

$$\begin{aligned} S_r &= \lambda T_r \\ &= \frac{\lambda b_r}{W_r} \end{aligned}$$

Substituting for W_r from equation 3.1

$$\begin{aligned} S_r &= \frac{2\lambda b_r}{(1-\theta)W} \\ &= \frac{2b_r S}{(1-\theta)b_m} \\ &= \frac{2\eta S}{1-\theta} \end{aligned} \tag{3.3}$$

The average reservation delay is obtained from simulation results of the single channel using the CSMA/CD. The delay-throughput curve is normalized with respect to the packet transmission time on the channel under consideration, namely, T_r for our case. Therefore the delay of the reservation channel as a function of the normalized input rate S_r and the normalized propagation delay a_r on the request channel is

$$
\begin{aligned}
D_r &= D_{CSMACD}(S_r, a_r)T_r \qquad (3.4)\\
&= D_{CSMACD}(S_r, a_r)\frac{S_r}{\lambda}\\
&= D_{CSMACD}(S_r, a_r)\frac{2\eta S}{(1-\theta)\lambda}\\
&= D_{CSMACD}(S_r, a_r)\frac{2\eta b_m}{(1-\theta)W} \qquad (3.5)
\end{aligned}
$$

where S_r is given in equation 3.3 and a_r is expressed as

$$
\begin{aligned}
a_r &= \frac{\tau}{T_r}\\
&= \frac{(1-\theta)\tau}{2\eta}\frac{W}{b_m} \qquad (3.6)
\end{aligned}
$$

where τ is the end-to-end propagation delay on the channel.

Message channel Delay

In order to estimate the queueing delay D_q in the message channel we assume that the output of the reservation channel is Poisson distributed with mean λ requests per second. After scheduling conflicts have been resolved, all the users can be grouped into a single queue as shown in figure 3.3. The effect of dynamic assignment can be modeled using a multiple servers model. We therefore model this queue by an M/M/m queueing system. We assume the system is in steady state condition and that an infinite buffer is available.

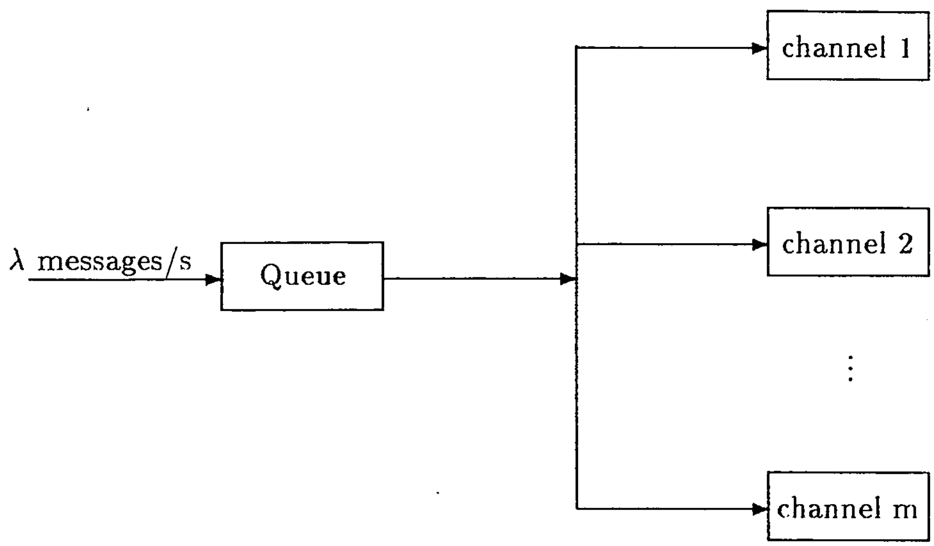

Figure 3.3: A typical M/M/m queueing system

From the above assumptions, the traffic intensity u is given by

$$u = \frac{\lambda}{\mu}$$

where μ is the average service rate for each channel and the channel utilization ρ_m is

$$\rho_m = \frac{\lambda}{\mu m}$$

From [8] the probability that all the channels will be busy when a station makes a request is

$$P_b(m, \rho_m) = \frac{\left(\frac{m\rho_m}{m!}\right)\left(\frac{1}{1-\rho_m}\right)}{\sum_{k=0}^{m-1} \frac{(m\rho_m)^k}{k!} + \left(\frac{(m\rho_m)^m}{m!}\right)\left(\frac{1}{1-\rho_m}\right)} \tag{3.7}$$

where m is the number of message channels. The average waiting time in the buffer is then given by

$$D_q = \frac{P_b(m, \rho_m)}{m(1 - \rho_m)\mu} \tag{3.8}$$

The total delay on the message channel is therefore the sum of the queueing delay D_q, and transmission time for one message packet T_m

$$D_m = D_q + T_m \tag{3.9}$$

Taking the propagation delay τ for the request, answer and message packets into consideration, the average total message delay is therefore

$$\begin{aligned} D &= D_r + D_m + 3\tau \\ &= D_r + D_q + T_m + 3\tau \end{aligned} \tag{3.10}$$

The above analysis is used to obtain the results in the next chapter.

Chapter 4

RESULTS

4.1 Discussion of results

The delay throughput characteristics are obtained for a Local Area Network with a total channel capacity of 10Mbits/s and a reservation channel using non-persistent CSMA/CD with normalized propagation delay $a_r = 0.05$. The average message packet size is assumed to be 1000 bits and $\tau = 1.0\mu s$. Results are obtained for two cases

1. when the total bandwidth available is evenly divided into m channels.

2. when the the reservation channel bandwidth is different from that of the message channels.

Figure 4.1 shows the normalized message transmission delay as a function of various values of m with evenly divided bandwidths. It is observed that the maximum throughput increases with the number of channels.

From figures 4.2 to 4.6 the delay-throughput is illustrated as a function of θ (fraction of the message transmission to total channel capacity) with the CSMA/CD/IC protocol from [11] for different number of channels. The results obtained show better performance can be obtained from the reservation protocol when θ is increased.

Finally, figure 4.7 compares the performance of our protocol for different values of m for fixed $\theta = 0.9$. The results show that for $\theta = 0.9$, two channels gives the best performance. This is due to the fact that the message transmission time increases as the number of channels increases and so does the total message delay. However, in an integrated services network, the performance could be improved by increasing the number of channels, and dedicating certain services to particular channels. For example, circuit and packet switching services could be implemented this way.

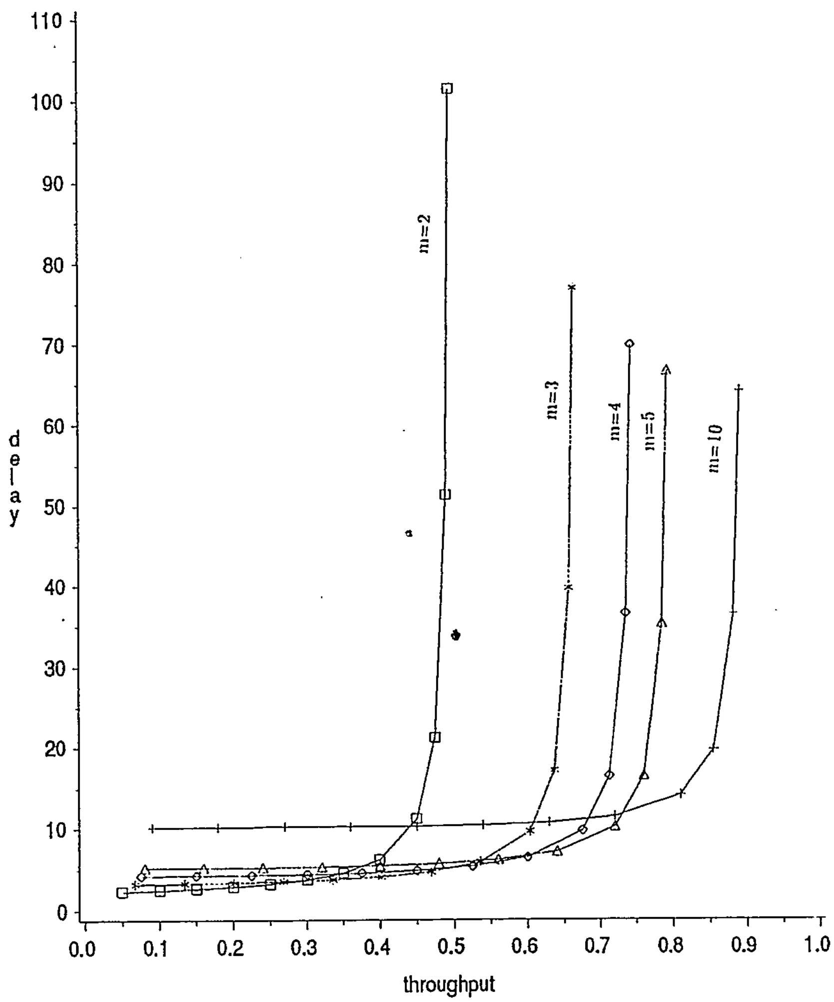

Figure 4.1: Delay-throughput characteristics of reservation protocol as a function of m.

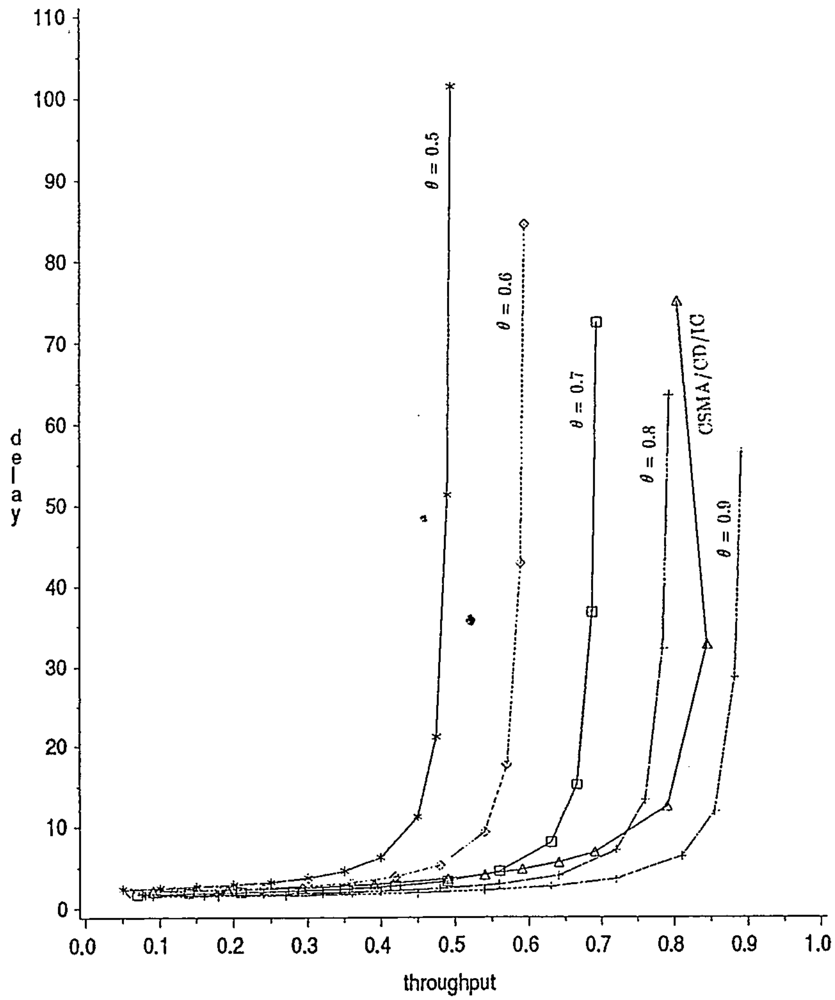

Figure 4.2: Delay-throughput comparisons: Reservation and CSMA/CD/IC for m=2

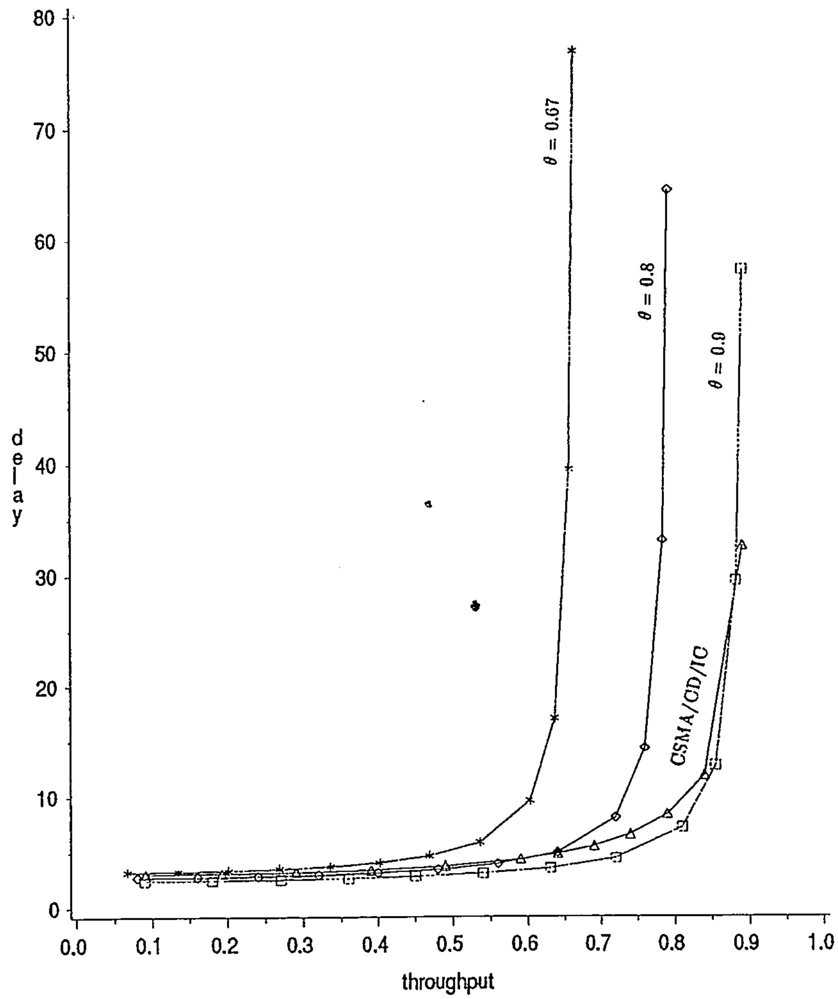

Figure 4.3: Delay-throughput comparisons: Reservation and CSMA/CD/IC for m=3

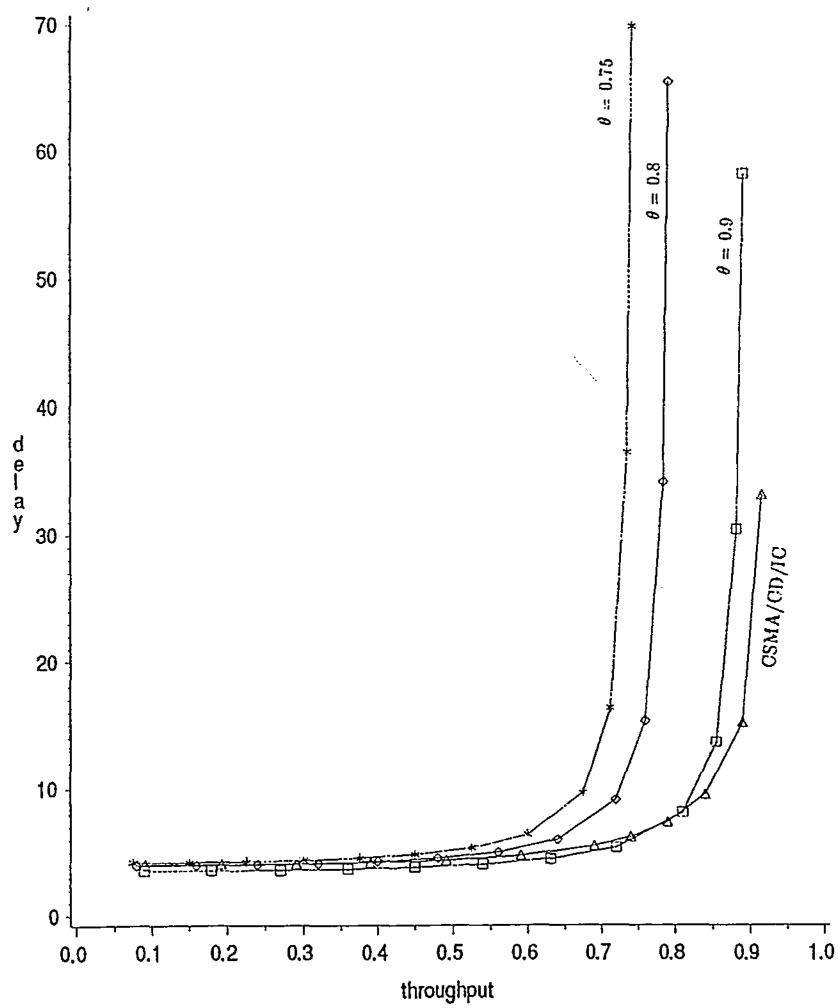

Figure 4.4: Delay-throughput comparisons: Reservation and CSMA/CD/IC for m=4

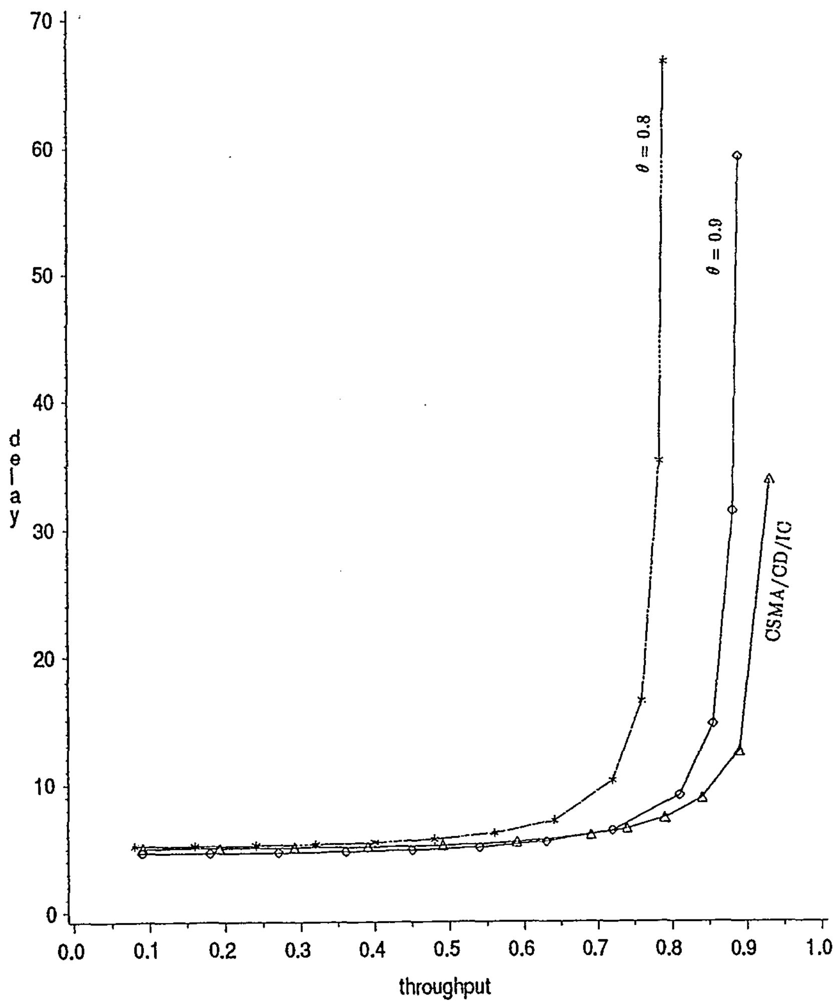

Figure 4.5: Delay-throughput comparisons: Reservation and CSMA/CD/IC for m=5

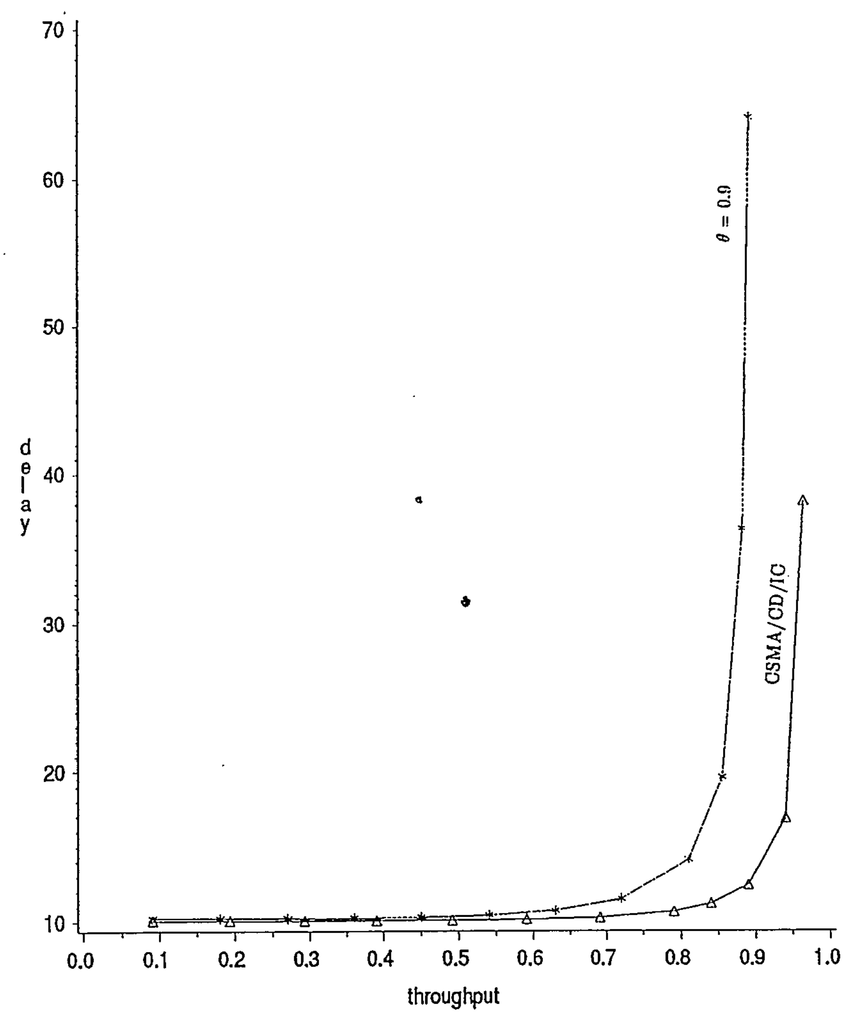

Figure 4.6: Delay-throughput comparisons: Reservation and CSMA/CD/IC for m=10

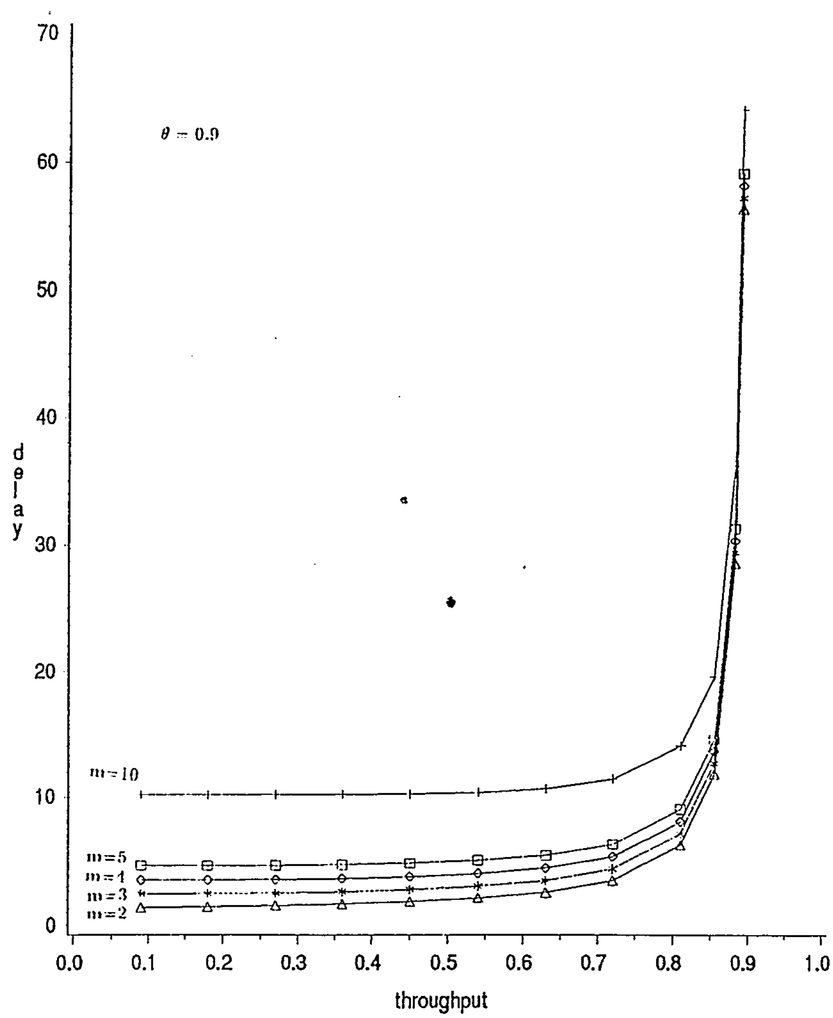

Figure 4.7: Delay-throughput characteristics of reservation scheme as a function of m

Chapter 5

CONCLUSION

In this thesis a dynamic reservation multichannel access technique combined with the CSMA/CD protocol has been proposed and analyzed. It has been shown that using the reservation scheme for multichannels increases the maximum throughput achievable by increasing the number of channels. It has also been shown that the reservation scheme has the potential to improve the system performance in terms of the throughput and average message delay as compared to the CSMA/CD/IC protocol.

Suggestions for future work

- A study could be undertaken to examine the performance of other multiaccess schemes for multiple channels.
- The performance of the reservation scheme can also be investigated with some priority schemes for different traffic types.

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